CAPACITY FOR HOLDING SUSTAINED ATTENTION FOLLOWING COMMISSUROTOMY[1]

Leah Ellenberg and R. W. Sperry

(Division of Biology, California Institute of Technology)

INTRODUCTION

Recent "vigilance" studies of Dimond (1976, 1977) on commissurotomized patients have led to the inference that hemisphere disconnection leaves radical deficits in conscious attention in the form of gaps or lapses in awareness and sufficiently striking to be labeled "black holes of consciousness". These gaps in awareness are reported to extend often over many seconds and to be numerous and prominent primarily in the left hemisphere in performances requiring sustained attention beyond 10 minutes. The surgically separated left hemisphere was also found to be susceptible to rapid fatigue when forced to maintain a focus of attention. The power to hold sustained mental concentration in the normal intact brain was accordingly interpreted to be predominantly a function of the right hemisphere.

Confirmation of the foregoing would represent a significant addition to the hemisphere disconnection syndrome and also to current notions of the neural mechanisms of attention and consciousness, as well as carrying important implications concerning hemispheric specialization. These conclusions are in line with some evidence in the literature suggesting that left hemisphere dysfunction, more than right, disrupts arousal and consciousness (Serafetinides, Hoare and Driver, 1964, 1965; Rosadini and Rossi, 1967; Schwartz, 1967; Albert, Silverberg, Reches and Berman, 1976). On the other hand, they are countered by numerous observations of long sustained mental performance in commissurotomy patients by the left as well as the right disconnected hemisphere working independently in a large variety of test conditions over many years of testing.

Because of the apparent contradiction and general importance of the

[1] This work was supported by grant No. 03372 from the National Institute of Mental Health of the United States Public Health Service and by the F. P. Hixon Fund of the California Institute of Technology.

Cortex (1979) *15*, 421-438.

phenomenon, it was deemed desirable that it be further investigated under a wider range of conditions. The tasks used by Dimond requiring sustained passive attention with infrequent stimulation and response give little information concerning the nature of mentation during the long periods between signals. It is hardly possible to be sure whether the observed periodic failures in response are due to true gaps in general awareness as described in the vigilance literature (Bills, 1931) or merely to shifts of attention as noted by Broadbent (1953).

The present experiments compared the performance of the disconnected hemispheres on tasks requiring a continued focus of attention sustained for periods up to 1 hour in varied patterns of right-left alternation and bilateral simultaneity. Both passive and active programming on the part of the subject were included. The combined results suggest an interpretation in terms of lowered efficiency in focal and detectional components of sustained attention and in related decision making mechanisms in both hemispheres rather than in terms of intermittent gaps in left hemisphere awareness. A preliminary report was presented earlier (Sperry and Ellenberg, 1977).

Materials and Method

Subjects

The subjects tested were five complete commissurotomy patients of Vogel and Bogen with presumed complete section of the corpus callosum, anterior and hippocampal commissures (A.A., L.B., N.G., N.W. and R.Y.) and two partial commissurotomy patients (N.F. and D.M.) in whom the surgical sections were similar to the above except that the posterior third of the corpus callosum was left uncut. The surgery and case histories of these patients have been detailed elsewhere (Gordon, Bogen and Sperry, 1971; Milner and Taylor, 1972; Bogen and Vogel, 1974). Ten right handed, non-brain-injured adult males whose mean age was 24.5 years were used as controls.

Procedure

The testing procedures included two series of tasks that demanded sustained, focused attention but differed in the amount of active involvement on the part of the subject. The first was a series of tactual sorting tasks which required an active concentration process with sustained, subject-paced manual responding to an unvarying, tedious, but attention-demanding task. This series was followed by two tactual signal detection tasks similar to those employed by Dimond (1977) involving a more passive vigilance with manual responses to random, experimenter-paced tactual signals.

Tactual sorting

Subjects performed prolonged monotonous sorting tasks that were simple and routine but sufficiently demanding to require close attention throughout the

entire period of performance which usually lasted from 45 minutes to 1 hour. Any lapse of consciousness of more than a half-second duration should have been manifest as sorting errors or as pauses or even full cessation of the sorting performance.

Seven tactual sorting tasks were administered in which the subject sat blindfolded at a table directly in front of three stationary plastic containers 13 cm × 23 cm × 8 cm deep with a heavy steel base for stability. One was placed horizontally within easy reach of both hands centered between the other two which were positioned vertically in front of the subject's left and right hands. The central container was filled with two kinds of objects which were similar in weight and overall dimensions but different in shape. The side containers, empty at the start of each task, were divided into identical top and bottom compartments by means of a divider which extended 2 cm above the height of the container to assure easy location and identification of the separate compartments by touch. The subject was instructed to remove objects one at a time from the central container and to drop one type of item into the top compartment and the other into the bottom compartment of the side container, with left and right hands sorting into left and right side containers, respectively. The containers were lined with soft felt to reduce auditory cues.

A few demonstration and practice trials were given at the start until the subject was able to perform a criterion of 8 consecutive correct trials. Subjects were then instructed to begin the task, sorting as rapidly as possible without stopping to correct errors. Scores were obtained by counting the number of correct and incorrect items dropped into each compartment. The tester and often a second observer kept notes regarding the quality of perfomance. The sorting requirements were made progressively more difficult in successive tasks or more demanding in particular phases of the performance in order to test different hypotheses as these developed from preceding data. Specific details for each task are described separately below in context with the results.

Tactual signal detection

The tactual signal detection tasks were designed to assess ability to sustain attention under conditions where the subject was not actively engaged in motor activity but simply sat passively attending to changes in sensory (tactile) input in a setup designed to replicate that of Dimond (1977) in which gaps in conscious awareness had been reported previously. The subject sat facing a screen with the hands extended under and behind the screen resting upon two vibrating finger signal keys 30 cm apart to left and right on a wooden panel. The keys were fixed to vibrating audio speaker elements connected via an amplifier to a signal generator set to transmit a continuous vibration of 10 Hz. The key movement was silent and undetectable by any but tactile cues. With the middle finger of each hand resting comfortably on left and right keys, respectively, the subject was instructed to indicate with a manual signal of the corresponding hand each time a cessation of vibration was felt. The experimenter, sitting out of the subject's view behind the screen, controlled the signal (cessation of vibration) by depressing the right, left, or both of two control buttons which cut off the vibration for a discrete time period (1/2 second to 2 seconds). Trials with bilateral signals were added in the present study to allow for improved assessment of asymmetries in response capacity and unilateral extinction with simultaneous stimulation of both hemispheres. Left, right, or bilateral signals were given in a predetermined quasi-random order

with delays between signals preset to vary irregularly from 15 to 45 seconds. If any unilateral or bilateral signal was missed, it was repeated at 2-second intervals until it was detected or until 10 consecutive failures to respond occurred. Further details for the two versions of the signal detection tasks employed are described in context below.

Results

Tactual sorting: Unimanual

Task U1:

The first three sorting tasks, presented to the five complete commissurotomy subjects, were unimanual, with one hand sorting at a time. In the first of these, Task U1, subjects sorted continuously for three-minute periods, starting with the right hand and switching hands after each three-minute period. The objects sorted were 1/4″ hex-head bolts and 5/16″ hex nuts, each weighing 5 g. Without the subject's knowledge, the first few trials after switching hands were considered practice, with corrections being offered until 8 consecutive correct trials were achieved. The sorting continued until 10 three-minute periods were completed with each hand. The total task time including interperiod practice was approximately 70 minutes.

In Task U1, all subjects showed an ability to continue the sorting performance (at their top speed) throughout the 70 minutes with no apparent breakdowns in speed or rhythm of performance that might indicate gaps in conscious awarness. As shown in Table I, the right hand performed somewhat faster than the left in all of these right-handed subjects except for A.A., who has repeatedly demonstrated sensory and motor deficits in his right hand since the commissurotomy (Nebes and Sperry, 1971).

Error rates on Task U1 are shown in Table II. The error scores express the number of objects placed incorrectly with each hand as a percentage of the total number of objects sorted by the subject with that hand. Four of the five subjects tested demonstrated more right-handed than left-handed errors. For all subjects, the great majority of errors did not occur at random but, instead, in successive sequences of 3 or more when the subjects apparently forgot which item should go in which compartment and consistently reversed the correct assignment These reversals of sorting set lasted from several trials to over two minutes, averaging approximately 20 seconds, and were usually concluded by spontaneous shifts back to the correct sorting set. They occurred with little or no change in motor activity, which continued at a steady rate for each subject. In general, subjects showed no fatigue effects with sustained performance in either hemisphere. A comparison of error scores between the first and second half of the task for each hand revealed no increase in error rate for any subject except R.Y., whose right-handed errors were almost all in the second half.

TABLE I

Sorting Rates on Unimanual and Bimanual Sorting Tasks

	Subjects	Mean number of beads placed per minute									
		Task U1		Task B1		Task B2		Task B3		Task B4	
		Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand
Total commissurotomy	A.A.	8.1	13.4	8.7	8.8	7.7	7.7	6.8	6.8	10.3	10.5
	L.B.	24.9	20.7	20.5	20.5	23.6	23.4	16.5	16.4	26.7	26.7
	N.G.	30.2	21.9	29.0	32.1	29.7	29.1	23.6	22.6	28.1	28.1
	N.W.	38.2	35.3	34.4	32.7	35.9	32.6	26.1	25.9	37.9	28.3
	R.Y.	32.4	28.5	21.1	31.1	26.7	30.8	9.1	20.4	28.1	30.2
	Mean	26.7	23.9	22.7	25.2	24.7	24.7	16.4	18.4	26.2	24.8
Partial commissurotomy	N.F.			15.1	15.1						
	D.M.			14.2	14.3						
	Mean			14.6	14.7						
Control group	Mean			32.8	32.7						
	Range			27.0-40.0	27.0-40.2						

TABLE II

Error Rates of Complete Commissurotomy Subjects on Unimanual Tactual Sorting

Subjects	Percentage of total beads sorted which were placed incorrectly						Visual signals missed on Task U3	
	Task U1		Task U2		Task U3			
	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand
A.A.	16.8	0.8	16.8	0.4	0.0	0.9	0	0
L.B.	2.3	0.3	1.7	0.9	0.8	0.0	1	1
N.G.	47.2	8.4	16.9	0.0	16.0	1.4	1	0
N.W.	0.2	1.5	2.4	4.5	0.4	4.9	1	0
R.Y.	20.8	1.3	0.1	0.6	3.7	19.8	0	0
Mean	17.5	2.5	7.6	1.3	4.2	5.4	3	1

Task U2:

In Task U2 the subjects were required to combine the basic sorting performance of Task U1 with added continuous silent counting of the sorting trials. In this task, as well as in the remaining sorting tasks, the objects used were two kinds of beads of similar overall size (3/8″ diameter) and weight (0.5 g) with one being spherical and smooth and the other cylindrical in shape with rough ridges. The beads were tactually distinguishable but more similar in shape than the objects used in Task U1. Instead of switching hands at a signal from the experimenter, subjects were instructed to keep count of the sorting trials themselves and to switch hands every third, fourth, up to every tenth trial. The number to be sorted before switching hands was increased at a rate determined by each subject's ability. Usually after having demonstrated mastery of the performance with both hands for at least five minutes, the subject was told to increase the number counted without a break in sorting. Total task duration varied for each subject but was always between 45 and 75 minutes.

As shown in Table II, there is no evidence of a group trend towards greater right-handed error rates on Task U2, with each subject tending towards an individual pattern in lateralization of errors. Reversals of sorting set as observed in Task U1 occurred also on task U2, persevering through the switching of hands so that erroneous sorting with one hand was interrupted every few trials by correct sorting with the other hand. In general, subjects again showed good levels of sustained attention throughout Task U2 demonstrating no consistent group decline in performance or increase in the number of reversals of set with either hand during as much as 75 minutes of continuous sorting.

Task U3:

Task U3 combined continuous unimanual sorting with a visual signal detection task, thereby requiring both active concentration and passive vigilance. The subjects were not blindfolded during this task, but instead sorted with their hands behind a 94 × 76 cm screen on which was mounted a small (7 cm long) arrow that could be moved silently from behind the screen by the experimenter to point to right or left. Subjects were instructed to sort continuously while watching the arrow and to switch hands at each change in the direction of the arrow which was controlled by the experimenter and shifted irregularly after 3-30 trials. Sorting continued for one hour with no rest periods. Record was kept of the number of beads placed correctly and incorrectly as well as the number of signals missed (i.e., where the subject continued sorting with the wrong hand after the arrow had switched direction).

As shown in Table II, error rates on Task U3 fail to show a group trend toward lateralized deficits. As in Task U2, reversals of set were evident with each hand and were sometimes interspersed with correct sorting by the other hand. Levels of sustained attention were again generally maintained well throughout one hour of continuous sorting. As can be seen in Table II, almost no signals were missed by any subject during the task, indicating good sustained vigilance in conjunction with continuous motor activity.

Tactual sorting: Bimanual

Although the unimanual sorting series failed to reveal fatigue effects as demonstrated by a deterioration of sorting performance over time or discrete gaps in conscious awareness as demonstrated by fluctuations in rate or rhythm of sorting, it might be objected that one hemisphere could "turn off" intermittently and rest while the other was working. Furthermore, the reversals of sorting set which were seen in both hemispheres indicated possible problems in some aspects of focussed attention which warranted closer examination. Accordingly, we turned to tasks that involved simultaneous sorting with both hands thereby excluding the possibility of alternate relaxation in the mechanisms of attention. Bimanual sorting also minimized any chance of assistance by an uninvolved hemisphere through ipsilateral motor control or cross-cueing.

Task B1:

The first bimanual task, Task B1, was given to the five complete commissurotomy patients, two partial commissurotomy patients and ten right-handed controls. The task was similar to Task U1 except that both hands sorted beads simultaneously. Subjects were instructed to use both hands at the same time rather than alternately. Sorting was interrupted briefly at three-minute intervals to change side containers and refill the central container, at which time several practice trials were allowed with each hand to reinforce the correct sorting set. The number of sorting periods was reduced to five for split-brain patients so that total task time was approximately 25 minutes. A normal control group was tested to provide comparison for sorting and error rates and evaluate the possibility of lateralized concentration deficits in the intact brain. The controls performed a lengthened version of Task B1 with 10 three-minute sorting periods so that total task time was approximately 50 minutes.

Table III shows sorting errors of complete and partial commissurotomy patients as well as controls on Task B1. Four of the complete commissurotomy subjects sorted a greater percentage of beads incorrectly with the right than with the left hand, with L.B. and N.W. showing reversals of sorting

TABLE III

Error Rates on Bimanual Sorting Tasks

	Subjects	Percentage of total beads sorted which were placed incorrectly							
		Task B1		Task B2		Task B3		Task B4	
		Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand
Total commissurotomy	A.A.	0	0.8	17.2	0.9	4.9	0	0	1.6
	L.B.	15.3	0.7	1.7	0.3	40.5	21.9	1.5	0.8
	N.G.	5.3	4.2	49.7	4.4	21.3	4.3	3.9	4.5
	N.W.	8.9	2.7	0.9	1.4	0	3.9	2.5	1.7
	R.Y.	1.9	1.3	1.5	23.6	2.2	4.4	3.1	1.0
	Mean	6.3	1.9	14.2	6.1	13.8	6.9	2.2	1.9
Partial commissurotomy	N.F.	0	0						
	D.M.	5.6	4.2						
Control group	Mean	0.3	0.6						
	Range	0-1.1	0-1.3						

set with the right hand that appeared intermittently from task onset. In the normal control group, this error pattern was reversed, with mean error rate of the left hand being significantly greater than that of the right ($t = 2.1$, $p \leqslant .05$). No subject in the partial commissurotomy or control group showed any pattern of sequential errors or reversals of set during bimanual sorting, with two consecutive errors being the maximum observed. General fatigue over time did not contribute to the observed error patterns of split-brain or control groups with no significant differences in sorting speed or error rates evident between first and second half of the tasks.

As shown in Table I, the mean sorting rate of the total commissurotomy group is below that of the control group, despite the fact that the former subjects had had practice sorting on the three unimanual tasks. An outstanding feature of sorting rate in split-brain subjects as compared to partial commissurotomy or control subjects is that three of the five sorted at a different rate with each hand on Task B1, demonstrating a clear difference in motor speed and rhythmicity between two simultaneously performing hands despite initial instructions and periodic reminders to sort with both hands together. N.G. and R.Y. show a particularly interesting pattern in that the left hand increased

in speed from the unimanual to the bimanual task, actually sorting faster than the right hand when both worked together. Only A.A. and L.B. retained synchrony during bimanual sorting, reducing the rate of both hands to the level of their slower hand in unimanual sorting.

As on Task U1, then, the complete commissurotomy group demonstrated more errors and instances of set reversal by the right hand than by the left on Task B1. To further investigate these right-handed deficits as well as the dissynchronous motor behavior revealed, the five complete commissurotomy subjects were given three additional bimanual sorting tasks designed to assess the difficulty of different aspects of Task B1 for each hemisphere.

Task B2:

Task B2 was similar to Task B1 but was designed to introduce increased complexity only to the sensory discrimination and decision making components of the initial bimanual task while retaining an identical form of response sequence. The subjects were required to sort three shapes of beads, two shapes to be placed in the top compartment of the response container and one to be placed in the bottom with all other task instructions remaining unchanged from those of Task B1.

An examination of error rates on Task B2, shown in Table III, reveals much inter- and intra-subject variability in task performance. Set reversals were evident with the right and the left hand, although never with both simultaneously. Error rates again tended to remain stable or decrease with increasing time spent at the task. Motor speed also remained stable at each subject's maximum capacity throughout the task although Table I indicates that dissynchronous motor behavior between two simultaneously active hands was again evident in N.W. and R.Y.

Task B3:

Task B3 added a motor step to the response pattern of Task B1. Although the two stimuli sorted were identical to those in the first bimanual sorting task, the subject was required to press one of two counters, each located adjacent to one of the response containers, with the heel of the hand prior to placing the bead into the appropriate compartment of the response container on each trial.

Table III indicates that results were essentially the same on Task B3 as on Task B2 with variability between subjects, reversals of set, and stable error rates throughout the task. Table I reveals that the added motor steps in the response sequence of Task B3 resulted in lower sorting rates for all subjects with dissynchronous motor behavior evident only in R.Y.

Task B4:

Because all the bimanual sorting tasks involved short interruptions with one-handed practice every three minutes, it could be argued that these "breaks" may have increased the ability to sustain attention. To eliminate this possibility, Task B4 was introduced. Subjects were given the same instructions as for Task B1 but were told they would sort continuously for 1/2 hour and were not to interrupt their performance for any reason. Central and side containers were changed by the experimenter every 3 minutes as the subject worked without causing an interruption in sorting.

All subjects were able to maintain stable sorting speed and error rates during 1/2 hour of continual sorting. No subject interrupted the task except for N.W. who requested a 3-minute break after 25 minutes to take medication as she reportedly sensed the onset of a seizure. Table III indicates that uninterrupted sorting actually resulted in generally reduced error rates with fewer set reversals. As shown in Table I, dissynchronous motor behavior still occurred in R.Y. and in N.W., who sometimes sorted two beads at once with her faster, more efficient right hand.

Tactual signal detection

On the tactual sorting tasks, neither deficits nor asymmetries in the capacity for sustaining mental concentration were strikingly apparent in performances of commissurotomy patients. In order to better determine possible reasons for the disparity between these results and those of Dimond (1976, 1977), we turned to tasks closely replicating those used by Dimond which differed from the foregoing in that they did not involve continual motor activity. Two tasks requiring a state of sustained sensory alertness for signal detection were presented to complete commissurotomy patients, partial commissurotomy patients and to ten normal control subjects.

Task D1:

With middle fingers resting on the vibrating keys behind a screen, subjects were instructed to raise the index finger of the hand under which they felt the vibration cease (the signal). Signal length was set at 1/2 second and practice trials were begun. Practice was continued until three consecutive correct detections were made under each of the signal conditions (left, right, and both hands). If repeated failures occurred, signal length was increased in 1/2-second increments until the criterion was reached. Dimond did not report the background vibration amplitude used in his study. In the present task, background vibration amplitude setting, which varied from 1 to 10, was preset at 4 and increased one setting at a time until the subject could

reliably feel the vibration and its cessation during practice. The resulting amplitude of background vibration and duration of signal for each subject, as shown in Table IV, were close to threshold so that both patients and controls were uncertain of the accuracy of their responses. The continual vibration with minimal extraneous stimulation or distraction provided a highly monotonous environment conducive to somnolence. For the five complete and two partial commissurotomy patients tested, Task D1 lasted for 30 minutes. Since Dimond and Beaumont (1973) had found lateralized decrements in normal subjects after nearly one hour of visual signal detection, control subjects were administered Task D1 for a 1-hour period. Controls wore blindfolds to minimize extraneous visual stimulation thereby increasing task monotony and the possibility of demonstrable fatigue effects.

The performances of the five split-brain subjects indicate that they generally had difficulty maintaining passive alertness during the half-hour duration of the task. R.Y. became so motorically agitated after 15 minutes of task performance that the task was discontinued. N.G. complained of a "real bad headache" after 25 minutes. L.B. and N.W. each dropped off to sleep for several seconds during the latter half of the task, ceasing response to signals under any condition until a deliberate noise by the experimenter caused arousal with spontaneous comments from the subjects to the effect that they "must have fallen asleep". A.A., although maintaining response capability on Task D1, fell asleep during an earlier pilot version of the signal detection task. The two partial commissurotomy patients also demonstrated some difficulty, with N.F. asking many questions despite reminders to remain silent and D.M. remarking after task completion that he often sensed himself falling asleep but was awakened by the signals. No control subject had any comparable problem in one hour of task performance. However, the combination of a uniform background stimulus, lack of distraction and uncertainty of the correctness of responses apparently rendered the task disagreeable for most control subjects. Many of them complained to the examiner after task completion about the difficulty of maintaining alertness under the monotonous, sleep-inducing conditions, especially with no feedback about response accuracy.

Mean signals missed for the four commissurotomized patients who completed Task D1, the two partial commissurotomy patients and the ten control subjects are shown in Table IV. Error scores are for all "left", "right" and "both" handed signals missed, including those presented repeatedly when the initial signal was missed, and are divided into consecutive 15-minute periods of task performance. For the complete commissurotomy patients, a comparison of signals missed under the three signal conditions reveal a group trend towards more errors to "right" than to "left" or "both" signals ($F = 4.22$; d.f. = 2,6; $.10 < p < .05$). In addition, right-handed errors increased significantly from the first 15-minute period to the second ($t = 3.04$, $p < .05$,

TABLE IV

Signals Missed on Task D1

	Subjects	Signal length in seconds	Amplitude setting	Total signals missed						Unilateral responses to bilateral signals	
				1st 15 minutes			2nd 15 minutes				
				Right hand	Left hand	Bilateral	Right hand	Left hand	Bilateral	Right	Left
Total commissurotomy	A.A.	1.0	7	8	3	1	14	5	1	3	12
	L.B.	0.5	4	21	1	2	61	3	8	1	7
	N.G.	1.0	5	31	0	0	70	0	0	1	3
	N.W.	2.0	7	1	2	0	18	11	10	7	0
	Mean	1.1	5.8	15.3	1.5	0.8	40.8	4.8	4.8	3.0	5.5
Partial commissurotomy	N.F.	1.0	9	18	1	1	32	9	1	8	5
	D.M.	1.0	7	2	1	0	4	2	0	0	0
Control Mean*		0.5	4	2.7	2.1	0.3	3.1	4.7	0.3	2.5	1.1
				3rd 15 minutes			4th 15 minutes				
				2.1	2.2	0.7	2.5	2.8	0.4	1.9	1.4

* n = 10.

one-tailed, d.f. = 3) whereas errors in the other two signal conditions increased somewhat but not significantly. Of the split-brain subjects, L.B. and N.G., who showed the greatest discrepancy between right versus left hand errors as well as the greatest increase in right-handed errors from the first to the second half of the task were, the only ones to show "gaps" in performance, i.e., failures to detect up to 10 consecutively presented signals. These gaps occurred with the right hand as early as 10 minutes after task onset for both subjects and increased in frequency with continued task performance. Each of the two partial commissurotomy patients showed a unique error pattern with the performance of N.F. being similar to that of the total commissurotomy group while the scores of D.M. resembled those of control subjects. On those bimanual signal presentations resulting in unimanual responses, A.A., L.B. and N.G. typically responded with the left hand while N.W. always perceived only the right-handed signal.

Control subjects showed no differences in error rates between the two hands, although they had significantly fewer errors when the signal was given to both hands ($F = 7.976$; d.f. = 2, 18; $p < .01$). Furthermore, the scores of intelligent normal subjects showed no decline over one hour of task performance, with stable error rates maintained throughout the task. No control subject showed any instances of failure to detect 10 consecutive signals with either hand. Unilateral responses to bilateral signals were infrequent with no lateralized pattern evident.

The above results were in agreement with those of Dimond to the extent of demonstrating a deficit in complete commissurotomy patients in sustaining attention during a passive signal detection task. However, the inferences regarding a right hemisphere locus of sustained attention and of gaps in consciousness in the left hemisphere were not confirmed. To test further for possible asymmetries in attentional capacity, Task D2 was devised. It was reasoned that left hemisphere attentional deficits might become manifest in increased reaction time (RT) latencies to right-handed signals and that the sensitive RT measure might reveal lateralized differences in normal subjects where they had failed to show in error rate measurements.

Task D2:

Task D2 was similar to Task D1 with subject's middle fingers resting on the vibrating signal keys. In addition, the index finger of each hand rested on a button wired to an RT recording apparatus. Subjects were asked to respond to the middle finger signals by depressing as soon as possible the button under the index finger of the hand through which the signal was detected. All subjects wore blindfolds to eliminate visual distractions as well as headphones through which they heard tape recorded white noise to eliminate the auditory stimuli associated with the RT monitor. Task D2 was administered to three complete commissurotomy patients (A.A., L.B. and N.G.) and to the ten normal controls. Since the gaps in right-hand performance had appeared in Task D1 within 10 minutes of task onset and because of the strong complaints about the tedium of Task D1, total task time was reduced to 20 minutes.

As shown in Table V, the performances of A.A. and L.B. were different on Task D2 than on Task D1. Only N.G. performed similarly with more right- than left-handed errors on both tasks. No subject showed gaps with either hand. Mean RTs were computed for all subjects based on error-free trials. Table V shows that all three split-brain patients showed increased RTs to right-handed as compared to left-handed signals, a difference evident from task onset and remaining stable throughout the task. Control subjects generally made fewer errors than split-brain subjects and showed no significant differences in error rates under the three stimulus conditions. As in Task

TABLE V

Signals Missed and RT On Task D2

Subjects	Total signals missed				Mean RT*	
	Right hand	Left hand	Bilateral	Total	Right hand	Left hand
Controls**	1.6	.7	0	2.4	1.124	1.133
Total commissurotomy						
A.A.	10	1	0	11	2.060	1.640
L.B.	0	8	6	14	1.382	1.016
N.G.	8	3	2	13	0.93	0.616
Mean	6	4	2.66	12.66	1.457	1.091

* In seconds.

** n = 10.

D1, bilateral signals evoked improved performance in controls, with no subject making an error under this condition. Control subjects showed no significant lateral differences in mean RT.

Discussion

The results confirm earlier indications (Sperry, 1974; Dimond, 1976, 1977) that commissurotomy patients show a weakened ability to sustain attention compared with normals. In the two passive signal detection tasks similar to those used by Dimond, the performance of the commissurotomy subjects deteriorated after 10-30 minutes whereas that of normals was maintained for one hour. This deficit appeared to reflect a decline over time in level of general attentive arousal or vigilance which in some instances extended to falling asleep.

In contrast, these same commissurotomy patients were able in all cases to sustain prolonged concentration and alertness for testing periods up to one hour on monotonous sorting tasks in which performance involved repeated sensory discriminations and sorting decisions with continual motor activity. Apparently, the continual proprioceptive and external stimulation and related central turnover engendered by the active performance helps to maintain arousal and mental concentration. Our results suggest that the

central mechanisms that mediate focusing and holding of an attentive set in the absence of such reinforcement normally involve the cerebral commissures and are markedly weakened by their surgical section. Extra-commissural brain damage and the anti-seizure medication in these same subjects cannot be ruled out as contributing factors since the effect was observed in one of the two partially commissurotomized subjects (N.F.) as well. Presumably, a difference in attentional capacity for active and passive tasks exists in the intact brain as well and was masked in our control subjects by a ceiling effect.

The earlier conclusion of Dimond that commissurotomy patients are afflicted by prominent gaps or holes in left hemisphere awareness are not confirmed by our results. None of the patients showed left hemisphere lapses in performance in any of the seven sorting tasks while maintaining alert attention and mental concentration for periods up to one hour. On the first of the two signal detection tasks, only two of the five total commissurotomy patients (L.B. and N.G.) showed significant left hemisphere lapses in performance similar to those observed by Dimond. However, a number of factors indicate that the unilateral gaps in performance even in these two cases are more properly explained in other terms. L.B. and N.G. were the only two subjects whose performance with the right hand was consistently inferior to that with the left throughout the active sorting. Furthermore, they had more right handed extinction to bilateral signals and longer right handed reaction time latencies on signal detection, all suggesting that the left hemisphere in these two patients is measurably less proficient than the right at the particular tasks involved. N.F., the partial commissurotomy patient who showed similar unilateral deficits, is known to have postsurgical left hemisphere damage (Gordon, Bogen and Sperry, 1971). The left hemisphere lapses in performance on signal detection in L.B., N.G. and N.F. would accordingly seem more parsimoniously explained in terms of a threshold effect from taxing demands on a less proficient left hemisphere.

Dimond's inference that the power of sustained mental concentration is primarily a function of the right hemisphere is also not supported in these findings. No consistent patient or control group differences in the ability of the hemispheres to maintain performance levels over time were evident in either active or passive tasks. In those instances where sustained mental concentration did weaken unilaterally in one of the commissurotomy patients during active sorting, it did so as often in the right hemisphere as in the left.

Unilateral reversals of sorting set during active sorting were displayed by all subjects with complete commissurotomy whereas such reversals were not observed in the patients with partial commissurotomy nor in normal controls. These reversals of cognitive set did not exhibit any predominant asymmetry, occurring in either hemisphere at different times. There were no indications that the reversals reflected gaps in awareness or a decline in

general levels of arousal since other concurrent aspects of the performance such as rate of sorting, accuracy of object placement and obedience to general task instructions remained unaffected on both sides. Any sustained cognitive drifting from the task at hand or a lowering of arousal should presumably have resulted in a more erratic performance instead of the systematic error patterns observed. The reversals seemed, instead, to reflect a unilateral slip or misfunction in an upper cognitive level of the performance hierarchy while proper organization at other levels was retained. That a reversal on one side did not spread to the other nor appear to influence the proficiency or error rate of the opposite hemisphere indicates that the upper level cognitive directives involved were operating independently in each hemisphere. These reversals illustrate the capacity of the surgically disconnected hemispheres to operate in parallel with opposing higher cognitive sets each demanding focused attention, and each carrying out mutually conflicting volitional decisions. Studies in progress indicate that normal subjects have great difficulty performing the same kind of reversed sorting intentionally on instructions whereas split-brain subjects execute such conflicting tasks easily and with little or no loss in speed or accuracy.

The lapses into left-right dissynchrony observed during bimanual sorting in three of the five complete commissurotomy subjects offer another indication of lateral independence in mechanisms for volitional and seemingly conscious performances operating in parallel in the two hemispheres. Motor dissynchrony of this kind was not observed in the partial commissurotomy patients nor in normals and seems not to have been described in other studies of bimanual motor performance in brain damaged or normal subjects (Cohn, 1951; Hausmanowa-Petrusewicz, 1959; Wyke, 1971). Simultaneous performance with dissimilar motor patterns in the two hands is extremely difficult for normals, musicians often requiring years of practice to master the ability. Since motor dissynchrony was observed in complete but not in partial commissurotomy patients, it appears that maintenance of this kind of motor symmetry can be mediated via fibers of the splenium (see also Preilowski, 1972).

As a rule, the faster hand slows during bilateral activities to perform synchronously with an impaired or slower limb both in brain damaged and in normal populations (Wyke, 1971). In contrast, both N.G. and R.Y. improved impressively with their slower left hands during bimanual performance, actually performing faster with the left than with the right hand when the two were dissynchronous. This striking result demonstrates that the disconnected left hemisphere, when not engaged in activity of its own, can nevertheless exert an inhibiting influence, probably operating through common subcortical mechanisms, which interferes with optimal motor performance by the partner hemisphere.

Summary

To assess the relative capacities of the two cerebral hemispheres to sustain prolonged mental concentration, the performance of commissurotomized patients and normal controls was tested on monotonous sorting and signal detection tasks. The two series of tasks all required the maintenance of focused attention but differed in the amount of motor activity involved. Results showed that attentional capacity was different for active than for passive tasks in the patient group. During the active sorting tasks, commissurotomy patients were able to sustain continuous attention for periods of up to an hour while in the passive signal detection tasks, a decline in general levels of arousal was evident within ten to twenty minutes. The maintenance of generalized attention with minimal proprioceptive and external stimulation was thus found to be markedly weakened following commissurotomy. Neither hemisphere was consistently inferior to the other in sustaining mental concentration. The unique ability of commissurotomy patients to efficiently carry out mutually conflicting volitional decisions while sorting with the hands simultaneously points up the role of the intact commissures in unifying attentional components of cognitive processing.

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